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Tsuchimoto et al.

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(54) **OPTICAL SENSOR DEVICE**

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This patent is subject to a terminal disclaimer.

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G01J 1/44 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01J 1/44*** (2013.01); ***A61B 5/02433*** (2013.01); ***A61B 5/14552*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC A61B 5/02433; A61B 5/14551; A61B 5/7203; A61B 5/02416; A61B 5/0261
See application file for complete search history.

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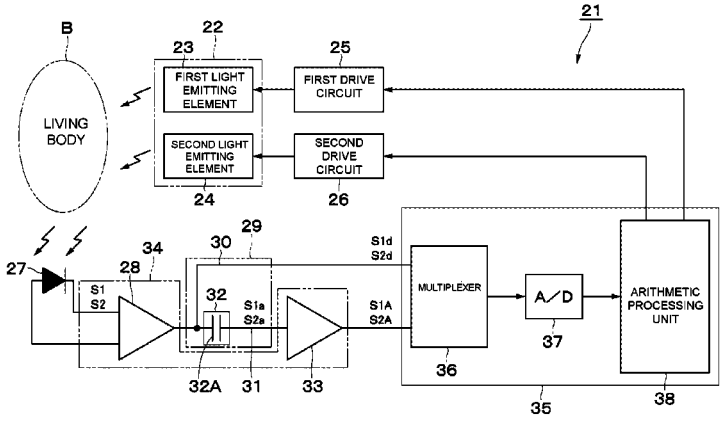
(57) **ABSTRACT**

An optical sensor device includes a light emitter for emitting, to a living body, lights having two wavelengths and blinking at a predetermined frequency, and a light receiver for receiving the lights from the living body. The light receiver outputs first and second detection signals corresponding to the respective wavelengths. A filter circuit extracts, from the first and second detection signals, modulation signals that are obtained with amplitude modulation of signals of the predetermined frequency. The modulation signals are amplified by a post-amplifier and are taken into an arithmetic processing unit after being converted to digital signals by an AD converter. The arithmetic processing unit calculates DC components and AC components of the first and second detection signals by employing the modulation signals converted the digital signals.

5 Claims, 10 Drawing Sheets



Related U.S. Application Data

continuation of application No. PCT/JP2012/055967, filed on Mar. 8, 2012.

(51) **Int. Cl.**

G01J 3/427	(2006.01)
G01N 21/25	(2006.01)
G01N 21/31	(2006.01)
A61B 5/1455	(2006.01)
A61B 5/024	(2006.01)
A61B 5/00	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 5/7203*** (2013.01); ***G01J 3/427*** (2013.01); ***G01N 21/256*** (2013.01); ***G01N 21/3151*** (2013.01); *A61B 5/6826* (2013.01); *A61B 5/6829* (2013.01); *G01J 2001/444* (2013.01)

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FIG. 1

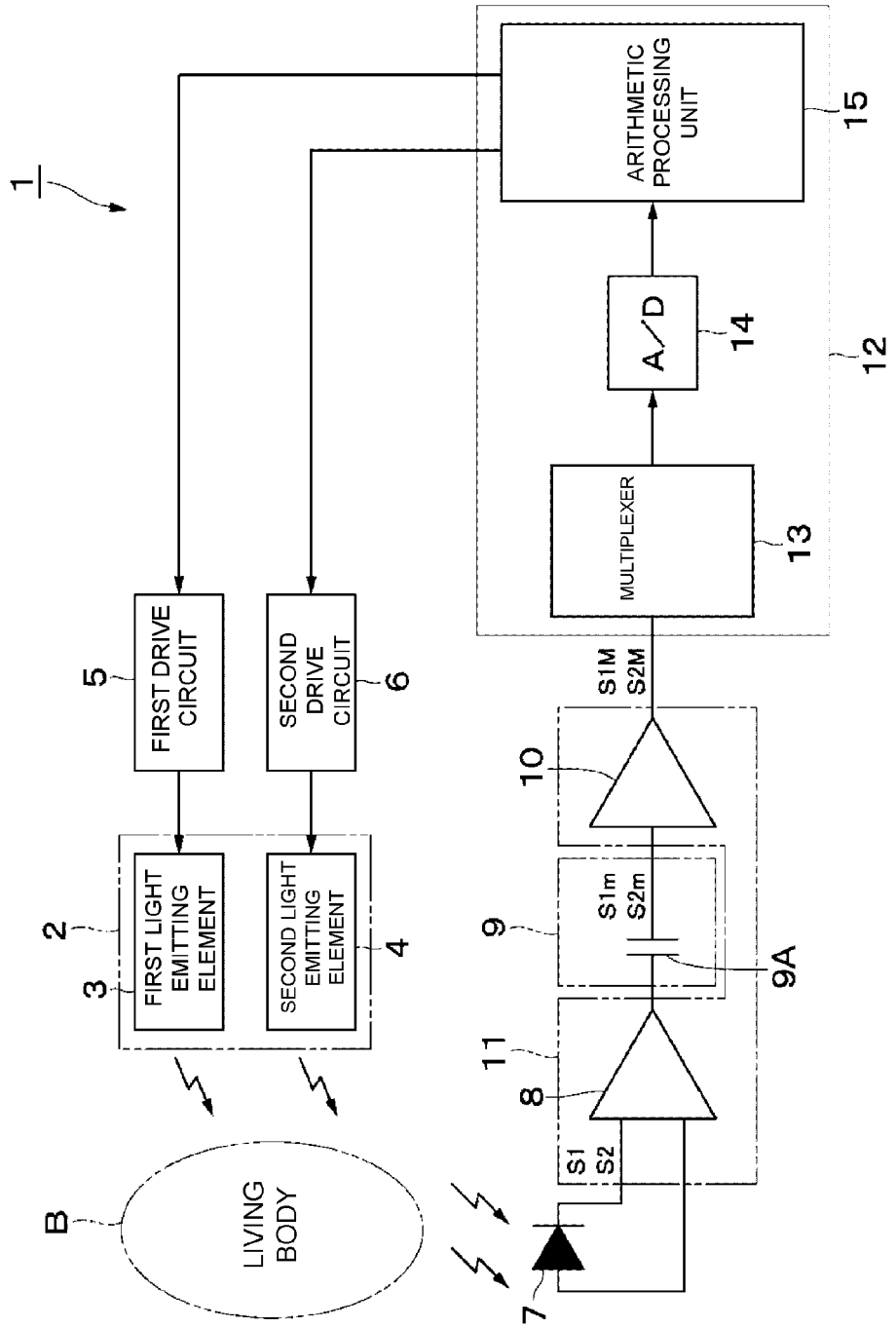
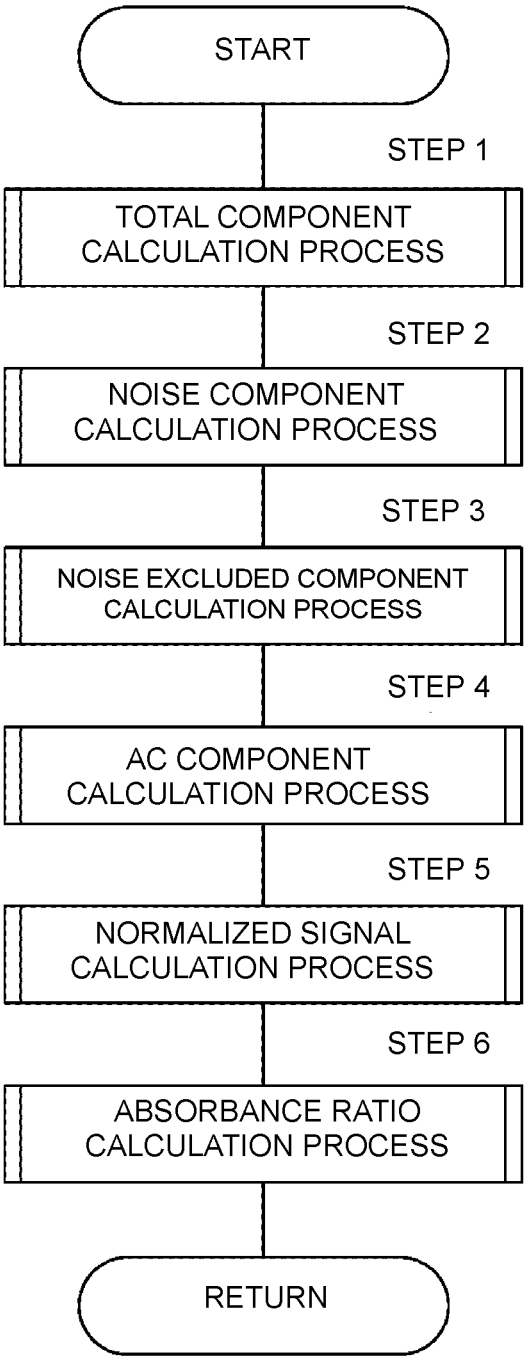

1
ARITHMETIC PROCESSING UNIT
15
A/D
14
12
MULTIPLEXER
13
S1M
S2M
FIRST DRIVE CIRCUIT
5
SECOND DRIVE CIRCUIT
6
10
S1m
S2m
9
9A
2
3
FIRST LIGHT EMITTING ELEMENT
SECOND LIGHT EMITTING ELEMENT
4
11
8
S1
S2
B
LIVING BODY
7

FIG. 2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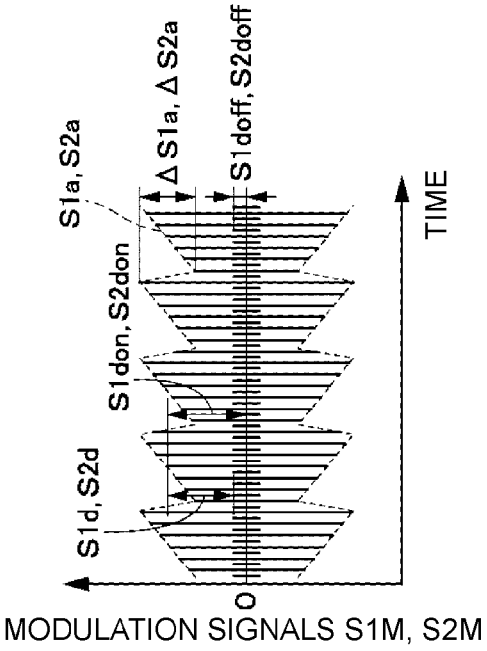
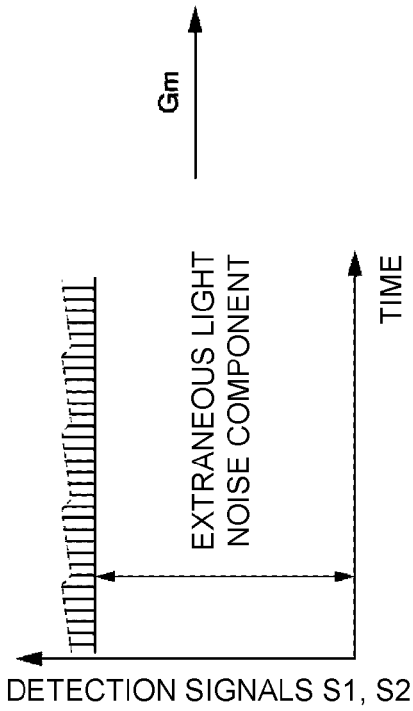
STEP 1
TOTAL COMPONENT CALCULATION PROCESS
STEP 2
NOISE COMPONENT CALCULATION PROCESS
STEP 3
NOISE EXCLUDED COMPONENT CALCULATION PROCESS
STEP 4
AC COMPONENT CALCULATION PROCESS
STEP 5
NORMALIZED SIGNAL CALCULATION PROCESS
STEP 6
ABSORBANCE RATIO CALCULATION PROCESS
RETURN

FIG. 3



MODULATION SIGNALS S1M, S2M



DETECTION SIGNALS S1, S2

FIG. 4

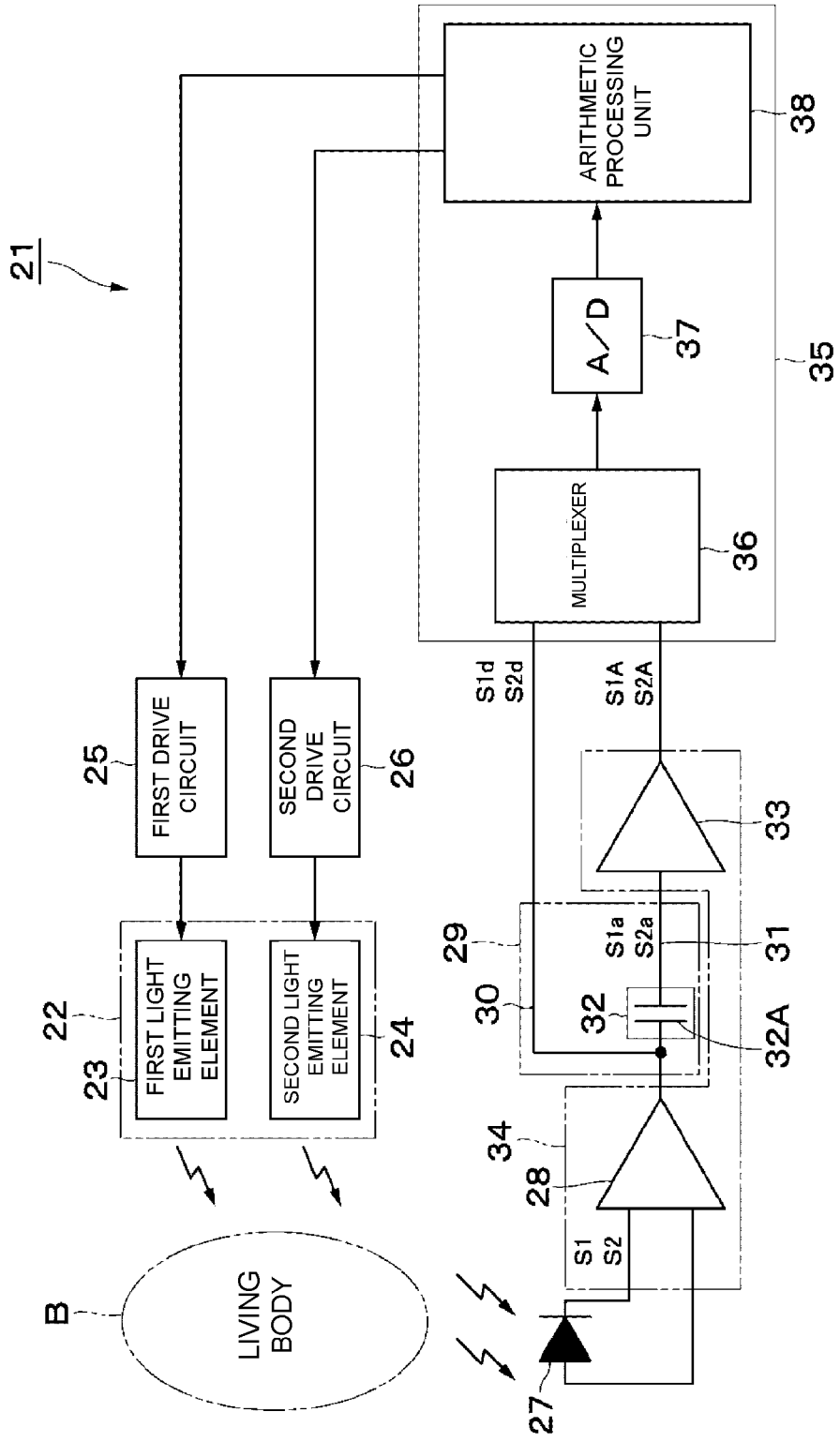
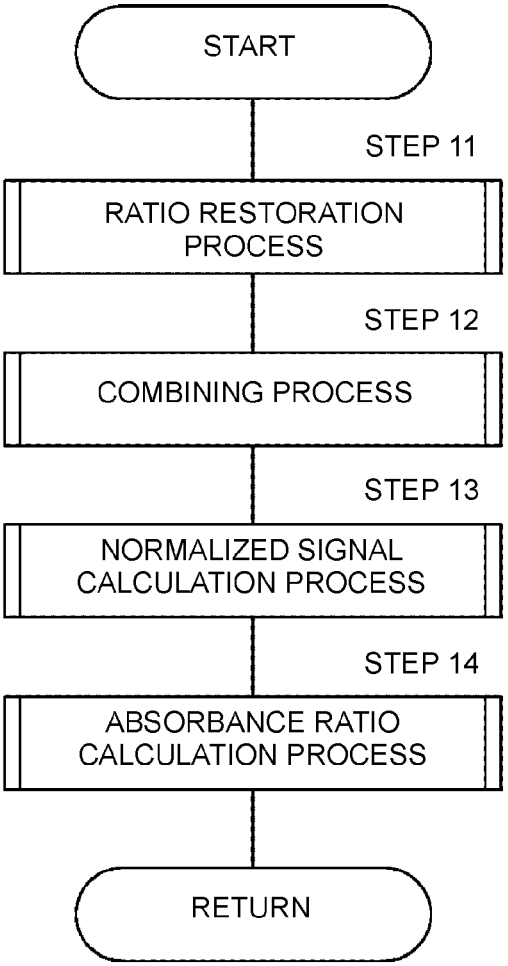

21
ARITHMETIC PROCESSING UNIT
38
A/D
37
35
MULTIPLEXER
36
S1d
S2d
S1A
S2A
FIRST DRIVE CIRCUIT
25
SECOND DRIVE CIRCUIT
26
33
29
S1a
S2a
31
30
32
32A
22
23
FIRST LIGHT EMITTING ELEMENT
SECOND LIGHT EMITTING ELEMENT
24
34
28
S1
S2
B
LIVING BODY
27

FIG. 5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STEP 11
RATIO RESTORATION PROCESS
STEP 12
COMBINING PROCESS
STEP 13
NORMALIZED SIGNAL CALCULATION PROCESS
STEP 14
ABSORBANCE RATIO CALCULATION PROCESS
RETURN

FIG. 6

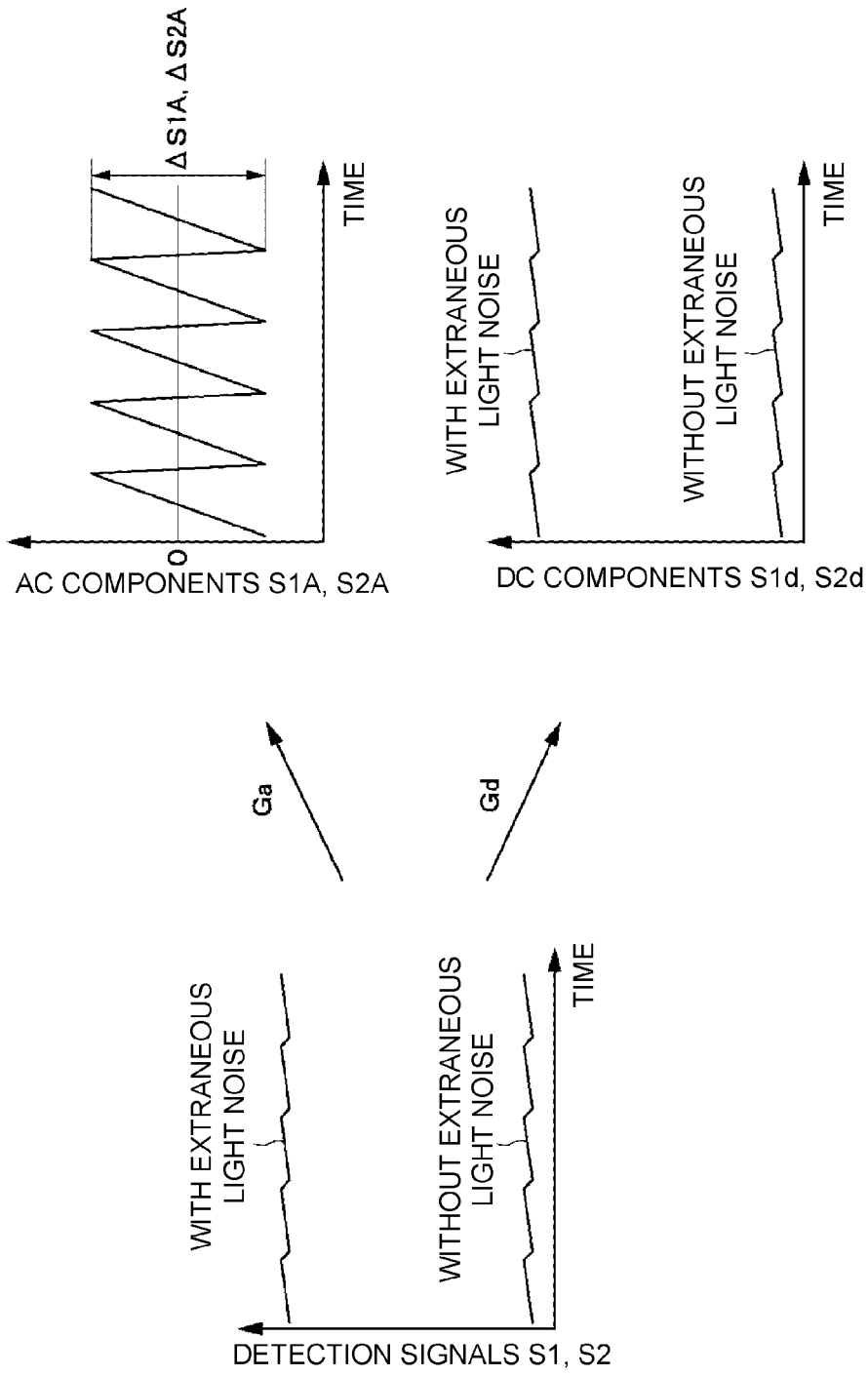

ΔS1A, ΔS2A
TIME
0
AC COMPONENTS S1A, S2A
WITH EXTRANEOUS LIGHT NOISE
WITHOUT EXTRANEOUS LIGHT NOISE
TIME
DC COMPONENTS S1d, S2d
Ga
Gd
WITH EXTRANEOUS LIGHT NOISE
WITHOUT EXTRANEOUS LIGHT NOISE
TIME
DETECTION SIGNALS S1, S2

FIG. 7

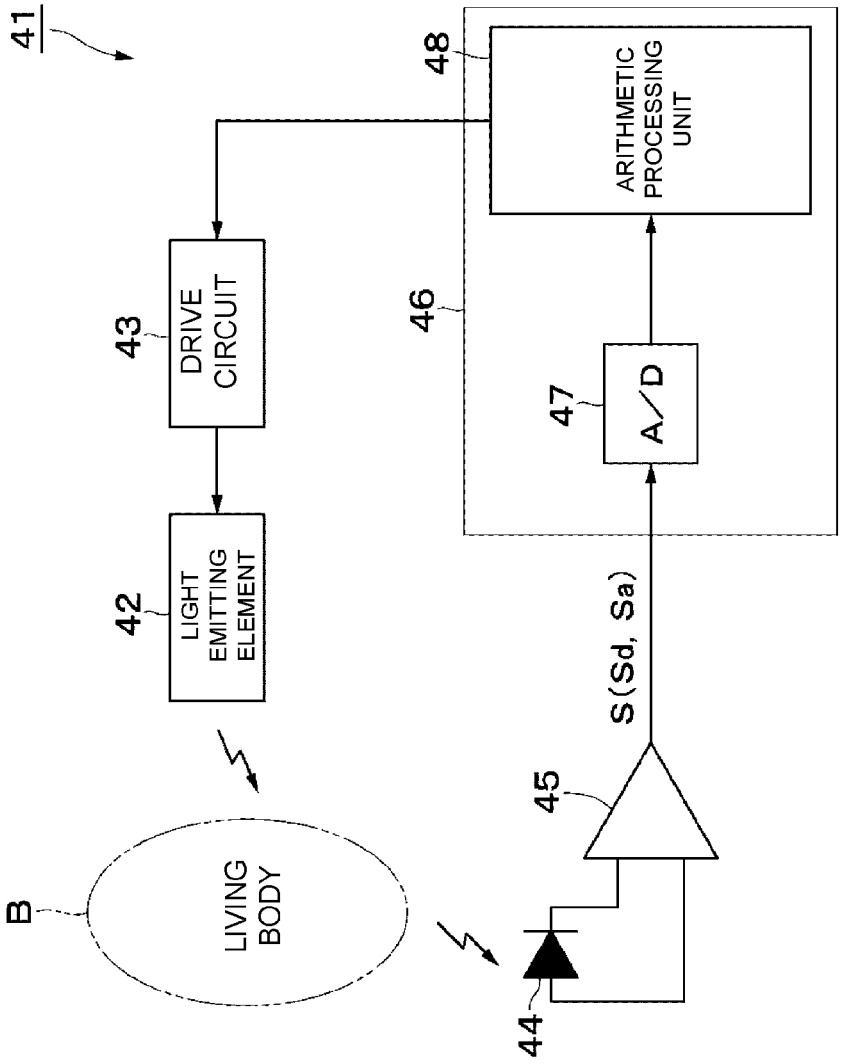

41
48
ARITHMETIC PROCESSING UNIT
43
DRIVE CIRCUIT
46
47
A/D
42
LIGHT EMITTING ELEMENT
S(Sd, Sa)
45
B
LIVING BODY
44

FIG. 8

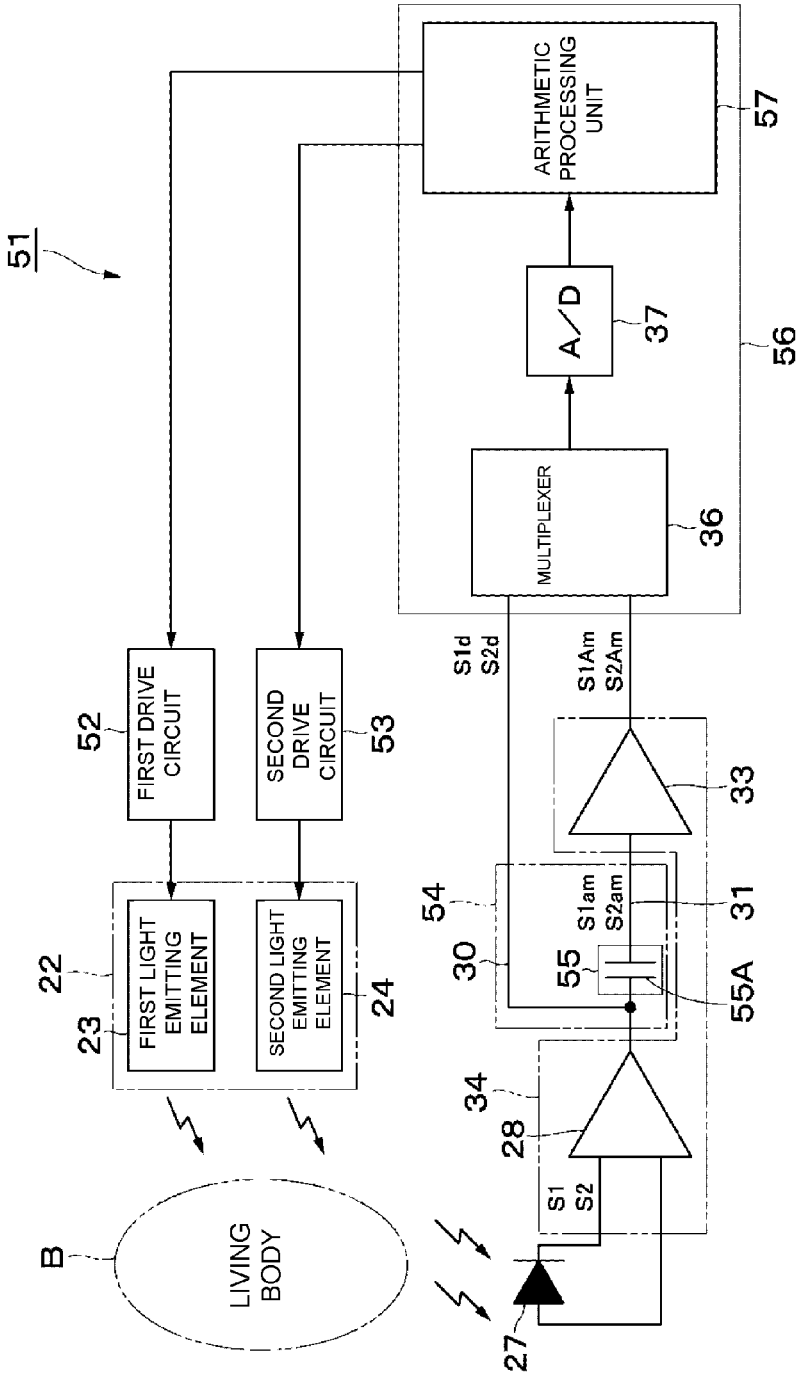

51
ARITHMETIC PROCESSING UNIT
57
A/D
37
56
MULTIPLEXER
36
S1d
S2d
S1Am
S2Am
FIRST DRIVE CIRCUIT
52
SECOND DRIVE CIRCUIT
53
33
54
S1am
S2am
31
30
55
55A
22
FIRST LIGHT EMITTING ELEMENT
23
SECOND LIGHT EMITTING ELEMENT
24
34
28
S1
S2
B
LIVING BODY
27

FIG. 9

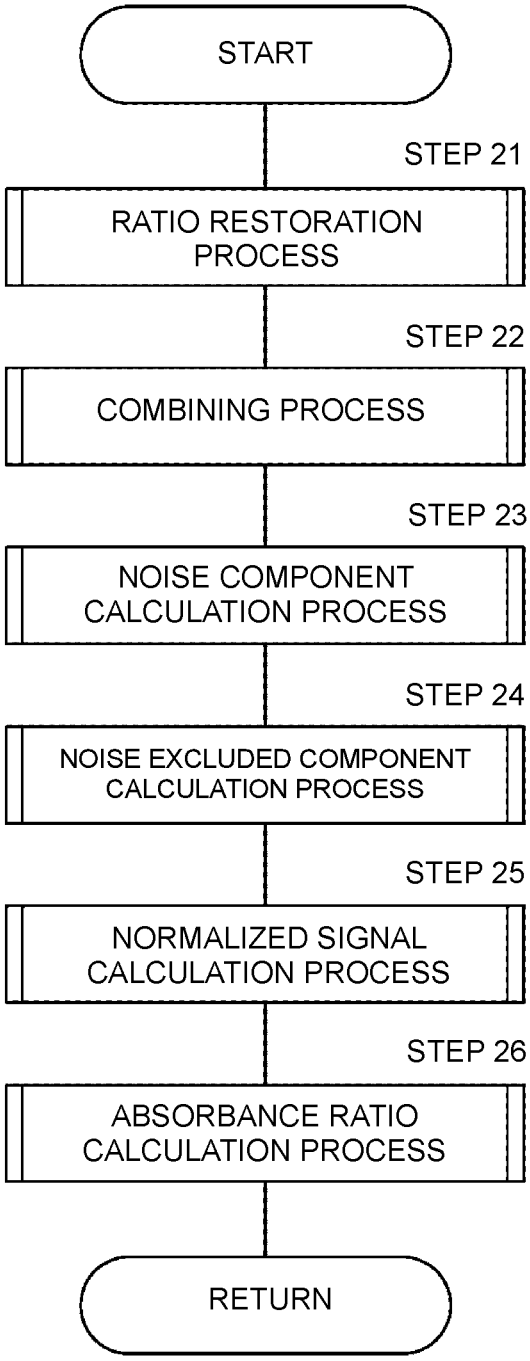
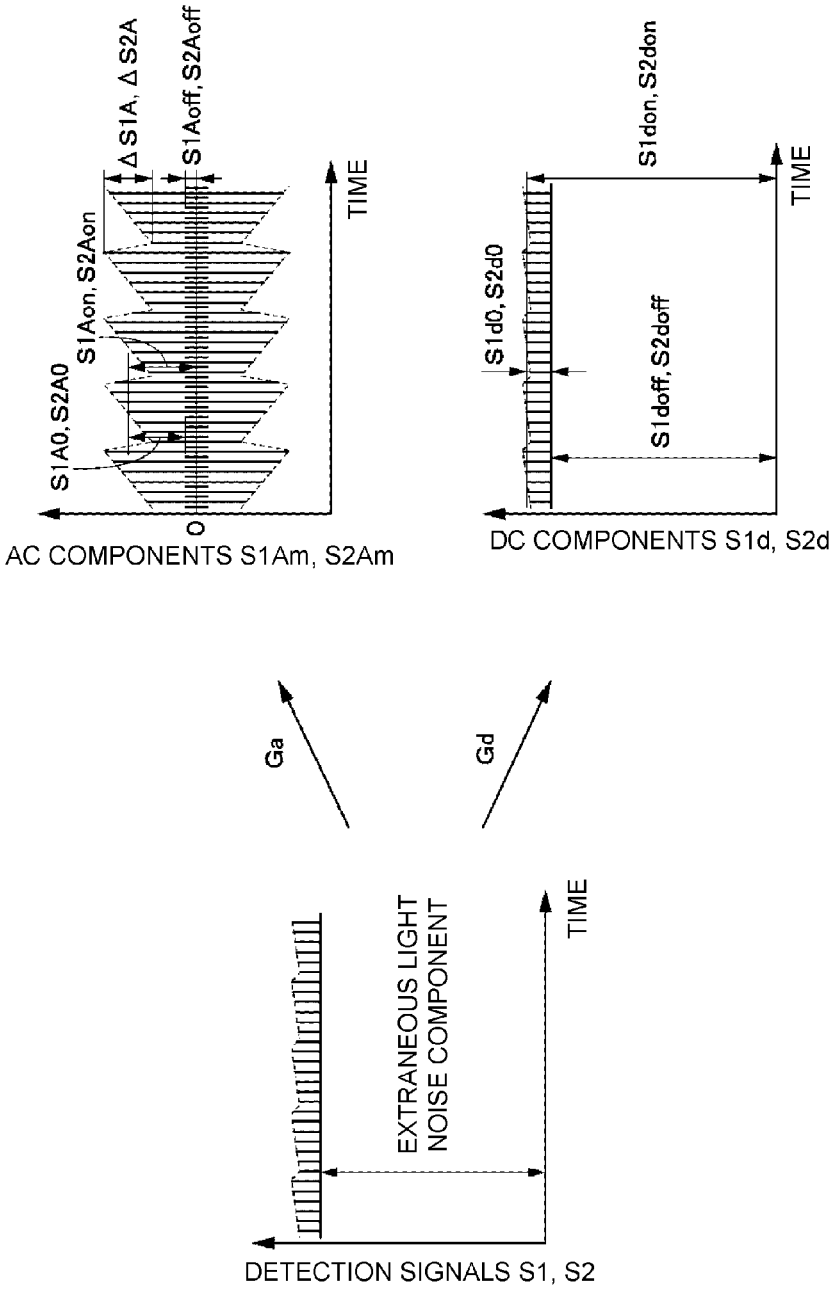

START
STEP 21
RATIO RESTORATION PROCESS
STEP 22
COMBINING PROCESS
STEP 23
NOISE COMPONENT CALCULATION PROCESS
STEP 24
NOISE EXCLUDED COMPONENT CALCULATION PROCESS
STEP 25
NORMALIZED SIGNAL CALCULATION PROCESS
STEP 26
ABSORBANCE RATIO CALCULATION PROCESS
RETURN

FIG. 10


S1A0, S2A0
S1Aon, S2Aon
Δ S1A, Δ S2A
S1Aoff, S2Aoff
TIME
O
AC COMPONENTS S1Am, S2Am
S1d0, S2d0
S1doff, S2doff
S1don, S2don
TIME
DC COMPONENTS S1d, S2d
Ga
Gd
EXTRANEOUS LIGHT
NOISE COMPONENT
TIME
DETECTION SIGNALS S1, S2

OPTICAL SENSOR DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is divisional of U.S. application Ser. No. 14/083,904, filed Nov. 19, 2013, which is a continuation of PCT/JP2012/055967 filed Mar. 8, 2012, which claims priority to Japanese Patent Application No. 2011-113482, filed May 20, 2011, and to Japanese Patent Application No. 2011-113485, filed May 20, 2011, the entire contents of each of which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to an optical sensor device including a light emitter and a light receiver.

BACKGROUND OF THE INVENTION

In general, there is known an optical sensor device of the type including a light emitter for emitting light to a measurement target, and a light receiver for receiving the light having been reflected by or transmitted through a living body (see, e.g., Patent Documents 1 and 2). Patent Document 1 discloses a technique of illuminating a finger or an earlobe of a living body with light emitted from a light emitter, receiving the light having been reflected by or transmitted through the living body by a light receiver, and detecting a photo-plethysmographic signal corresponding to the pulse of the living body based on an electrical signal output from the light receiver. In the technique of Patent Document 1, an amplifier is connected to the light receiver in order to amplify the electrical signal obtained through photoelectric conversion performed by the light receiver, and the amplified electrical signal is input to a processor to execute various types of signal processing.

Patent Document 2 discloses a technique of reflecting light from a reference light source by a scanning mirror, and receiving the reflected light by a detection element. In the technique of Patent Document 2, a signal from the detection element is separated into a direct current (DC) component and an alternating current (AC) component, each of which is converted to a digital signal by an AD converter.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 6-22943

Patent Document 2: Japanese Unexamined Patent Application Publication No. 2-13815

In the optical sensor device disclosed in Patent Document 1, the electrical signal output from the light receiver is amplified by the amplifier. At that time, because extraneous light, such as the sunlight, enters the light receiver in some cases, a noise component attributable to the extraneous light may be superimposed on the electrical signal. If the noise component attributable to the extraneous light becomes excessive, the amplifier would be saturated and a signal corresponding to the light emitted from the light emitter, such as a photo-plethysmographic signal, would not be detected correctively. Furthermore, if an amplification degree of the amplifier is reduced to prevent the saturation of the amplifier, a detected signal level would be reduced, thus causing a problem that sensitivity in light reception and detection accuracy of the photo-plethysmographic signal would degrade.

Moreover, conversion to the digital signal by the AD converter is required to execute the signal processing in the processor, etc. On that occasion, if the noise component attributable to the extraneous light is superimposed on the electrical signal from the light receiver, the electrical signal including the noise component is coded and, therefore, resolution of the AD converter has to be sufficiently increased with respect to a detection signal. For that reason, a dynamic range including the noise component as well needs to be prepared, thus causing another problem of raising the manufacturing cost.

On the other hand, Patent Document 2 discloses the technique of, after separating the signal from the detection element into the DC component and the AC component and amplifying them, converting each of those components to the digital signal by the AD converter. In the disclosed technique, however, the DC component and the AC component are separately subjected to signal processing, and an amplitude ratio between the DC component and the AC component is not restored to the same ratio as that when the signal has been output from the detection element. Accordingly, the converted digital signals cannot be directly applied to, for example, the case where the AC component is normalized using the DC component. In addition, in the optical sensor device disclosed in Patent Document 2, because the DC component and the AC component are detected in synchronism, the DC component and the AC component have to be converted to the respective digital signals by separate AD converters. Hence the manufacturing cost tends to increase.

SUMMARY OF THE INVENTION

The present invention has been accomplished in view of the problems described above, and an object of the present invention is to provide an optical sensor device, which can reduce the cost, and which allows an AC component to be normalized using a DC component.

(1) Accordingly, the present invention provides an optical sensor device comprising a light emitter for emitting light that blinks at a predetermined frequency set in advance, and outputting the light toward a measurement target, a light receiver for receiving the light emitted from the light emitter and reflected by or transmitted through the measurement target, and outputting an electrical signal obtained with photoelectric conversion of the received light, a filter circuit having, as a pass band, a band that corresponds to a part of the electrical signal output from the light receiver and that includes the predetermined frequency of the light emitter, and outputting a modulation signal modulated at the predetermined frequency of the light emitter, an amplifier for amplifying the modulation signal output from the filter circuit, an AD converter for converting the modulation signal, which is an analog signal after being amplified by the amplifier, to a digital signal, and an arithmetic processing unit for calculating a DC component and an AC component of the electrical signal based on the digital signal output from the AD converter.

According to the present invention, the light emitter emits the light at the predetermined frequency set in advance, and the filter circuit outputs the modulation signal, which is contained in the electrical signal output from the light receiver and which is modulated at the predetermined frequency of the light emitter. The modulation signal contains a DC component attributable to the light reflected by or transmitted through the measurement target, and an AC component corresponding to temporal changes in absorbance of the measurement target. The modulation signal is converted to a digital signal by the AD converter. Therefore,

the arithmetic processing unit can calculate the DC component and the AC component of the electrical signal, which is output from the light receiver, based on the modulation signal obtained as the digital signal. More specifically, for example, the arithmetic processing unit can calculate the DC component of the electrical signal by taking a time-average value of the modulation signal, and the AC component of the electrical signal by subtracting the DC component from the modulation signal. Hence the AC component can be normalized by employing the calculated DC component.

Furthermore, since the filter circuit can cut off signals of lower frequencies than the predetermined frequency, a cutoff frequency of the filter circuit can be increased to a value near the predetermined frequency of the light emitter. Accordingly, capacitance, for example, used in the filter circuit can be reduced, and reduction in size and cost can be realized.

Moreover, since the modulation signal output from the filter circuit is amplified by the amplifier, the modulation signal can be amplified up to a range near the amplitude range of the AD converter without being affected by signals of lower frequencies than the predetermined frequency of the light emitter, whereby a signal to noise ratio (S/N) can be stably ensured at a satisfactory level. In addition, since an amplitude range of the modulation signal input to the AD converter is stabilized, resolution per bit of the AD converter is widened. As a result, a bit width of the AD converter can be reduced, and the cost can also be reduced.

(2) In the present invention, the light emitter includes two light emitting elements emitting lights in first and second wavelength bands different from each other, the light receiver outputs first and second electrical signals corresponding respectively to the lights in first and second wavelength bands, and the arithmetic processing unit includes absorbance ratio calculation means for calculating an absorbance ratio of the measurement target based on a ratio of a first ratio between an amplitude of a first AC component and a first DC component, both obtained from the first electrical signal, to a second ratio between an amplitude of a second AC component and a second DC component, both obtained from the second electrical signal.

According to the present invention, since the light emitter includes two light emitting elements outputting the lights in first and second wavelength bands, and the light receiver outputs the first and second electrical signals corresponding respectively to the lights in first and second wavelength bands, the absorbance ratio calculation means in the arithmetic processing unit can calculate the absorbance ratio of the measurement target based on the ratio of the first ratio between the amplitude of the first AC component and the first DC component, both obtained from the first electrical signal, to the second ratio between the amplitude of the second AC component and the second DC component, both obtained from the second electrical signal. As a result, even when the light emission intensity of the light emitter and the light reception sensitivity of the light receiver are different between the first and second wavelength bands, the resultant influence can be reduced.

(3) In the present invention, the arithmetic processing unit includes DC component calculation means for calculating the DC component of the electrical signal by taking a time-average value of the modulation signal, and AC component calculation means for calculating the AC component of the electrical signals by excluding the DC component, which has been calculated by the DC component calculation means, from the modulation signal.

According to the present invention, the DC component calculation means in the arithmetic processing unit can calculate the DC component of the electrical signal by taking the time-average value of the modulation signal. Moreover, the AC component calculation means in the arithmetic processing unit can calculate the AC component of the electrical signal by excluding the DC component, which has been calculated by the DC component calculation means, from the modulation signal.

(4) In the present invention, the DC component calculation means is constituted by total component calculation means for calculating a total DC component based on both extraneous light noise and the light from the light emitter by employing a signal that is contained in the modulation signal and that is obtained during a light emission on-period of the light emitter, noise component calculation means for calculating a DC component attributable to the extraneous light noise by employing a signal that is contained in the modulation signal and that is obtained during a light emission off-period of the light emitter, and noise excluded component calculation means for calculating a DC component attributable to the light from the light emitter by excluding the DC component, which has been calculated by the noise component calculation means, from the DC component having been calculated by the total component calculation means.

According to the present invention, the total component calculation means in the DC component calculation means can calculate the total DC component based on both extraneous light noise and the light from the light emitter by employing a signal that is contained in the modulation signal and that is obtained during a light emission on-period of the light emitter. The noise component calculation means in the DC component calculation means can calculate the DC component attributable to the extraneous light noise by employing the signal that is contained in the modulation signal and that is obtained during a light emission off-period of the light emitter. The noise excluded component calculation means in the DC component calculation means can calculate the DC component attributable to the light from the light emitter by excluding the DC component, which has been calculated by the noise component calculation means, from the DC component having been calculated by the total component calculation means. As a result, the arithmetic processing unit can normalize the AC component by employing the DC component from which the influence of the extraneous light noise has been excluded, whereby the absorbance ratio can be obtained with higher accuracy.

(5) In the present invention, the optical sensor device further comprises a separation circuit including the filter circuit and separating the modulation signal and the DC component of the electrical signal, the AD converter converts, in addition to the modulation signal, the DC component of the electrical signal, which has been separated by the separation circuit, to a digital signal, and the arithmetic processing unit converts the modulation signal and the DC component of the electrical signal in accordance with an amplification factor of the amplifier such that an amplitude ratio between the modulation signal and the DC component of the electrical signal, both output as the digital signals from the AD converter, comes back to a state before the amplification by the amplifier, and calculates the AC component of the electrical signal based on the modulation signal obtained as the digital signal.

According to the present invention, since the electrical signal output from the light receiver is separated into the modulation signal containing the AC component and the DC component by the separation circuit, the modulation signal can be amplified by the amplifier separately from the DC

component of the electrical signal. The extraneous light noise is mainly superimposed on the DC component, and it is hardly superimposed on the modulation signal containing the AC component. Therefore, a degree of amplification for the modulation signal can be sufficiently increased with respect to the signal range of the AD converter that is a component of a digital processing unit. As a result, the signal to noise ratio (S/N) can be improved and stabilized.

Moreover, since the arithmetic processing unit converts the modulation signal and the DC component of the electrical signal, which are obtained as the digital signals, such that their amplitudes take the same ratio as that before the amplification by the amplifier, it is possible to restore the amplitude ratio between the DC component of the electrical signal and the modulation signal in the state just output from the light receiver. In addition, since the AC component of the electrical signal is calculated based on the modulation signal obtained as the digital signal, the AC component can be normalized by employing the DC component and the AC component after being restored.

(6) In the present invention, the arithmetic processing unit includes noise component calculation means for calculating the DC component attributable to the extraneous light noise based on a signal that is contained in the DC component of the electrical signal and that is obtained during a light emission off-period of the light emitter.

Here, the DC component of the electrical signal having been separated by the separation circuit contains components attributable to both the extraneous light noise and the light from the light emitter. Since the arithmetic processing unit can calculate the DC component attributable to the extraneous light noise by the noise component calculation means, the DC component attributable to the extraneous light noise can be excluded from the DC component output from the separation circuit. Thus, the AC component can be normalized by employing the DC component from which an influence of the extraneous light noise has been excluded, whereby the absorbance ratio can be determined with higher accuracy.

(7) The present invention further provides an optical sensor device comprising a light emitter for emitting light toward a measurement target, and a light receiver for receiving the light emitted from the light emitter and reflected by or transmitted through the measurement target, and outputting an electrical signal obtained with photoelectric conversion of the received light, wherein the optical sensor device further comprises a separation circuit for separating the electrical signal output from the light receiver into a DC component and an AC component, an amplification circuit for amplifying the DC component and the AC component, which have been separated by the separation circuit, at separate amplification factors, an AD converter for converting the DC component and the AC component, analog signals amplified by the amplification circuit, to digital signals, and an arithmetic processing unit for restoring the DC component and the AC component of the electrical signal by converting the DC component and the AC component output as the digital signals from the AD converter in accordance with the separate amplification factors of the amplification circuit such that an amplitude ratio between the DC component and the AC component output as the digital signals comes back to a state before the amplification by the amplification circuit.

According to the present invention, the electrical signal output from the light receiver is separated into the DC component and the AC component by the separation circuit, and the DC component and the AC component having been separated from each other are amplified at the separate amplification factors by the amplification circuit. Therefore, saturation of the amplification circuit due to the extraneous light noise can be suppressed by reducing the amplification factor of the DC component. On the other hand, the extraneous light noise is mainly superimposed on the DC component, and it is hardly superimposed on the AC component. Therefore, a degree of amplification for the AC component can be sufficiently increased with respect to the signal range of the AD converter that is a component of the digital processing unit. As a result, the signal to noise ratio (S/N) can be improved and stabilized.

Moreover, since the DC component and the AC component can be both amplified up to a range near the amplitude range of the AD converter, a signal to noise ratio (S/N) can be stably ensured at a satisfactory level for each of the DC component and the AC component. In addition, since an amplitude range of the signal input to the AD converter is stabilized, resolution per bit of the AD converter is widened. As a result, a bit width of the AD converter can be reduced, and the cost can also be reduced.

Furthermore, since the arithmetic processing unit converts the DC component and the AC component, which are obtained as the digital signals, such that their amplitudes take the same ratio as that before the amplification by the amplification circuit, it is possible to restore the amplitude ratio between the DC component and the AC component of the electrical signal in the state just output from the light receiver. Accordingly, the AC component can be normalized, for example, by employing the DC component and the AC component after being restored.

In the present invention, the light emitter may be configured to emit light blinking at a predetermined frequency set in advance. The separation circuit may be configured to have, as a pass band, a band including the predetermined frequency of the light emitter, and to output the AC component modulated at the predetermined frequency of the light emitter

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an overall block diagram of an optical sensor device according to a first embodiment.

FIG. **2** is a flowchart of a processing program executed by an arithmetic processing unit in FIG. **1**.

FIG. **3** is an explanatory view illustrating first and second detection signals and modulation signals in the optical sensor device in FIG. **1**.

FIG. **4** is an overall block diagram of an optical sensor device according to a second embodiment.

FIG. **5** is a flowchart of a processing program executed by an arithmetic processing unit in FIG. **4**.

FIG. **6** is an explanatory view illustrating a state where a DC component and an AC component are separated from each of first and second detection signals and are amplified by the optical sensor device in FIG. **4**.

FIG. **7** is an overall block diagram of an optical sensor device according to a comparative example.

FIG. **8** is an overall block diagram of an optical sensor device according to a third embodiment.

FIG. **9** is a flowchart of a processing program executed by an arithmetic processing unit in FIG. **8**.

FIG. **10** is an explanatory view illustrating a state where a DC component and an AC component are separated from

each of first and second detection signals and are amplified by the optical sensor device in FIG. **8**.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

Optical sensor devices according to embodiments of the present invention will be described in detail below with reference to the accompanying drawings.

FIG. **1** illustrates an optical sensor device **1** according to a first embodiment. The optical sensor device **1** detects, for example, a photo-plethysmographic signal (pulse wave signal) corresponding to the pulse of a living body B that is a measurement target.

A light emitter **2** is constituted by first and second light emitting elements **3** and **4** that output lights in first and second wavelength bands different from each other, respectively. The first and second light emitting elements **3** and **4** are each constituted by, e.g., a light emitting diode (LED). Herein, the first light emitting element **3** emits, e.g., red light in a band of 700 nm, and the second light emitting element **4** emits, e.g., infrared light in a band of 900 nm.

First and second drive circuits **5** and **6** are connected to the first and second light emitting elements **3** and **4**, respectively. The first and second light emitting elements **3** and **4** emit lights blinking in accordance with drive currents supplied from the first and second drive circuits **5** and **6**, respectively.

Herein, the first drive circuit **5** supplies a drive current that is pulse-modulated at a predetermined frequency f set in advance. The predetermined frequency f is set to a frequency higher than a signal frequency (e.g., about several Hz) of the photo-plethysmographic signal. Preferably, the predetermined frequency f is set to a value (e.g., about several hundreds Hz) higher than the signal frequency of the photo-plethysmographic signal by ten or more times within a range in which a processing circuit **12** is able to execute processing.

In addition, the predetermined frequency f is set to a value (e.g., f=100 Hz) sufficiently lower than the changeover cycle (e.g., 400 Hz) of an AD converter **14** such that conversion to a digital signal can be performed by the AD converter **14**.

The second drive circuit **6** also has substantially the same configuration as that of the first drive circuit **5**. Thus, the second drive circuit **6** supplies a drive current, which is pulse-modulated at the same predetermined frequency f as that in the first drive circuit **5**, to the second light emitting element **4**, thereby causing the second light emitting element **4** to emit blinking light. On that occasion, for example, the first and second light emitting elements **3** and **4** alternately emit the lights at timings different from each other.

However, when a light receiver **7** can separately receive the lights in the first and second wavelength bands, the first and second light emitting elements **3** and **4** may be configured to emit the lights at the same timing in synchronism. The first and second light emitting elements **3** and **4** may be each constituted using a vertical cavity surface emitting laser (VCSEL) or a laser diode (LD).

The light receiver **7** is constituted by, e.g., a light receiving element, such as a photodiode (PD). The light receiver **7** receives an optical signal and outputs it after photoelectric conversion to an electrical signal, e.g., a current signal or a voltage signal. More specifically, the light receiver **7** receives the lights emitted from the light emitting elements **3** and **4** and reflected by or transmitted through the living body B, converts the received lights to first and second detection signals S**1** and S**2** in the form of electrical signals, and outputs the detection signals S**1** and S**2** to a preamplifier **8**. Here, the first detection signal S**1** is a signal corresponding to the light in the first wavelength band, and the second detection signal S**2** is a signal corresponding to the light in the second wavelength band.

The light receiving element constituting the light receiver **7** may be a phototransistor, as another example. The light receiver **7** may be constituted using a single light receiving element, or using a plurality of light receiving elements, which receive lights in different wavelength bands by employing optical filters, for example.

The preamplifier **8** is constituted using, e.g., an operational amplifier. An input terminal of the preamplifier **8** is connected to the light receiver **7**. The preamplifier **8** amplifies the detection signals S**1** and S**2**, output from the light receiver **7**, at an amplification factor Gx and outputs the amplified signals to a filter circuit **9**.

The filter circuit **9** is constituted by a capacitor **9**A, which serves as a coupling capacitor connected between the preamplifier **8** and a post-amplifier **10**. The filter circuit **9** functions as a high-pass filter allowing passage of signals of frequencies, equal to or higher than the predetermined frequency f at which the first and second light emitting elements **3** and **4** emit the blinking lights. The cutoff frequency of the filter circuit **9** is set to a value as high as possible within a range allowing the signals of the predetermined frequency f to pass therethrough.

Because the light emitter **2** emits the lights blinking at the predetermined frequency f, the first and second detection signals S**1** and S**2** are each a signal obtained with amplitude modulation of the signal of the predetermined frequency f. On that occasion, because the capacitor **9**A cuts off signals of lower frequencies than the predetermined frequency f, the filter circuit **9** outputs modulation signals S**1***m* and S**2***m* that are obtained respectively from the first and second detection signals S**1** and S**2** through amplitude modulation at the predetermined frequency f.

The post-amplifier **10** is an amplifier for amplifying the modulation signals S**1***m* and S**2***m*. The post-amplifier **10** is constituted using an operational amplifier, for example, and it constitutes an amplification circuit **11** in combination with the preamplifier **8**. The post-amplifier **10** is connected to the output side of the filter circuit **9**. The post-amplifier **10** amplifies the first and second modulation signals S**1***m* and S**2***m* at an amplification factor Gy, and then outputs first and second modulation signals S**1**M and S**2**M after the amplification. Here, an amplification factor Gm of the first and second modulation signals S**1**M and S**2**M is set by both the preamplifier **8** and the post-amplifier **10**, and the amplification factor Gm is equal to the product of the amplification factor Gx and the amplification factor Gy (i.e., Gm=Gx× Gy). Thus, the amplification factors Gx and Gy of the preamplifier **8** and the post-amplifier **10** are set such that an amplitude range of each of the first and second modulation signals S**1**M and S**2**M has a value comparable to that of an input range of the AD converter **14**.

The processing circuit **12** is mainly constituted by a multiplexer **13**, an AD converter **14**, and an arithmetic processing unit **15**.

The multiplexer **13** connects the post-amplifier **10** to the AD converter **14**. Accordingly, the first and second modulation signals S**1**M and S**2**M output from the post-amplifier **10** are input to the AD converter **14** through the multiplexer **13**. For example, when the first and second light emitting elements **3** and **4** are driven to emit the lights alternately, the first and second modulation signals S**1**M and S**2**M can be input, as a series of time-divided signals, to the AD converter **14** in the form of a single unit. In such a case, the post-

amplifier **10** may be directly connected to the AD converter **14** by omitting the multiplexer **13**.

The AD converter **14** converts the first and second modulation signals S**1**M and S**2**M from analog signals to digital signals. At that time, the AD converter **14** converts, for example, only plus-side values of the first and second modulation signals S**1**M and S**2**M to digital signals. Moreover, the first and second modulation signals S**1**M and S**2**M are set by the preamplifier **8** and the post-amplifier **10** to values comparable to the input range of the AD converter **14**. Therefore, the AD converter **14** can convert the first and second modulation signals S**1**M and S**2**M to the digital signals by employing the entire input range thereof.

The arithmetic processing unit **15** is constituted by a microcomputer, for example. By executing a processing program illustrated in FIG. **2**, the arithmetic processing unit **15** calculates respective DC components S**1***d* and S**2***d* and respective AC components S**1***a* and S**2***a* of the first and second detection signals S**1** and S**2** based on the first and second modulation signals S**1**M and S**2**M output from the AD converter **14**, and further determines an absorbance ratio R**12** of the living body B. The processing program illustrated in FIG. **2** is executed, for example, each time the first and second modulation signals S**1**M and S**2**M are updated by the AD converter **14**.

In more detail, the arithmetic processing unit **15** executes a DC component calculation process illustrated in steps **1** to **3** of FIG. **2**, and calculates the respective DC components S**1***d* and S**2***d* a of the first and second detection signals S**1** and S**2** based on the first and second modulation signals S**1**M and S**2**M.

The first and second modulation signals S**1**M and S**2**M contain DC components, which are attributable to extraneous light noise, in addition to the DC components of the lights emitted from the light emitting elements **3** and **4** and reflected by or transmitted through the living body B. In view of the above-mentioned point, in a total component calculation process illustrated in step **1**, DC components S**1***d*on and S**2***d*on attributable to both the extraneous light noise and the lights from the light emitting elements **3** and **4** are calculated by extracting, from the first and second modulation signals S**1**M and S**2**M, signals obtained during light emission on-periods of the light emitting elements **3** and **4**, and by calculating respective time-average values of the extracted signals. At that time, each time-average value is calculated for a time corresponding to at least one cycle (e.g., about 1 sec) of the photo-plethysmographic signal, preferably two or more cycles, but the time is as short as possible within such a condition.

Next, in a noise component calculation process illustrated in step **2**, DC components S**1***d*off and S**2***d*off attributable to the extraneous light noise are calculated by extracting, from the first and second modulation signals S**1**M and S**2**M, signals obtained during light emission off-periods of the light emitting elements **3** and **4**, and by calculating respective time-average values of the extracted signals.

Next, in a noise excluded component calculation process illustrated in step **3**, the DC components S**1***d* and S**2***d* attributable to the lights from the light emitter **2** are calculated by excluding the DC components S**1***d*off and S**2***d*off, calculated in step **2**, from the DC components S**1***d*on and S**2***d*on calculated in step **1**, respectively.

Next, in an AC component calculation process illustrated in step **4**, the AC components S**1***a* and S**2***a* are calculated by extracting, from the first and second modulation signals S**1**M and S**2**M, signals obtained during light emission on-periods of the light emitting elements **3** and **4**, and by subtracting the DC components S**1***d*on and S**2***d*on, calculated in step **1**, from the extracted signals.

Next, in step **5**, a normalized signal calculation process is executed to normalize amplitudes ΔS**1***a* and ΔS**2***a* of the AC components S**1***a* and S**2***a* by employing the DC components S**1***d* and S**2***d*, respectively. More specifically, normalized signals S**10** and S**20** are calculated as first and second ratios by dividing the amplitudes ΔS**1***a* and ΔS**2***a* by the DC components S**1***d* and S**2***d*, respectively, in accordance with the following formula 1.

$$S10 = \frac{\Delta S1a}{S1d} \qquad S20 = \frac{\Delta S2a}{S2d} \qquad \text{[Math. 1]}$$

Next, in step **6**, an absorbance ratio calculation process is executed to calculate the absorbance ratio R**12** by employing the normalized signals S**10** and S**20**. More specifically, the absorbance ratio R**12** is calculated by dividing the normalized signal S**10** corresponding to the first wavelength by the normalized signal S**20** corresponding to the second wavelength in accordance with the following formula 2.

$$R12 = \frac{S10}{S20} \qquad \text{[Math. 2]}$$

The arithmetic processing unit **15** may produce, in addition to the absorbance ratio R**12**, biological information, such as a degree of oxygen saturation, acceleration pulse wave, and pulse fluctuation, based on the first and second detection signals S**1** and S**2**. Furthermore, the arithmetic processing unit **15** is connected to the first and second drive circuits **5** and **6** to establish synchronism between the light emission by the first and second light emitting elements **3** and **4** and the light reception by the light receiver **7** based on the operations of the first and second drive circuits **5** and **6**.

The optical sensor device **1** according to the first embodiment of the present invention is constituted as described above, and the operation of the optical sensor device **1** is described below.

First, a switch (not illustrated) of the optical sensor device **1** is turned on in a state that the light emitter **2** and the light receiver **7** are disposed near the living body B. Upon the turning-on of the switch, the first and second light emitting elements **3** and **4** of the light emitter **2** output the lights in the first and second wavelength bands, respectively. The light receiver **7** receives the emitted lights after being reflected by or transmitted through the living body B, and outputs the first and second detection signals S**1** and S**2** corresponding to the first and second wavelength bands, respectively. As illustrated in FIG. **3**, the modulation signals S**1***m* and S**2***m* are extracted from the first and second detection signals S**1** and S**2**, respectively, by the filter circuit **9** and are input to the processing circuit **12**. In the processing circuit **12**, the modulation signals S**1**M and S**2**M are converted to the digital signals by the AD converter **14**, and the DC components S**1***d* and S**2***d* and the AC components S**1***a* and S**2***a* are calculated by the arithmetic processing unit **15**. Other various processes are also executed by the arithmetic processing unit **15**.

Because the optical sensor device is configured here such that the light emitter **2** emits the lights at the predetermined frequency f and the filter circuit **9** outputs the modulation

signals S1*m* and S2*m* modulated at the predetermined frequency f of the light emitter **2**, the cutoff frequency of the filter circuit **9** can be set to a higher value, and the capacitance of the capacitor **9**A can be reduced.

To explain in more detail, the photo-plethysmographic signal is a low-frequency signal of about several Hz corresponding to the pulse of the living body. To separate the photo-plethysmographic signal, therefore, the cutoff frequency is to be set as low as about several Hz, and a capacitor having a large capacity of, e.g., about several hundreds μF is required. In contrast, in the first embodiment, the filter circuit **9** is just required to allow passage of signals of the predetermined frequency f, which is higher than the frequency of the photo-plethysmographic signal, in order to separate the modulation signals S1*m* and S2*m* modulated at the predetermined frequency f of the light emitter **2**. Therefore, the cutoff frequency of the filter circuit **9** can be set to a higher value, and the capacitance of the capacitor **9**A can be reduced to be smaller than 1 μF, for example. As a result, miniaturization and cost-reduction can be realized.

Moreover, the modulation signals S1M and S2M resulting from amplifying the modulation signals S1*m* and S2*m* contain not only the DC components S1*d* and S2*d* attributable to the lights from the light emitting elements **3** and **4**, but also the AC components S1*a* and S2*a* attributable to the photo-plethysmographic signal. The DC components S1*d* and S2*d* can be determined from respective time-average values of the modulation signals S1M and S2M. In the case of taking the time-average values of signals that are contained in the modulation signals S1M and S2M and that are obtained during the light emission on-periods of the light emitting elements **3** and **4**, the time-average values include the component attributable to the extraneous light noise in addition to the components corresponding to the lights from the light emitting elements **3** and **4**. Accordingly, in the first embodiment, of the modulation signals S1M and S2M, the DC components S1*d*off and S2*d*off resulting from time-averaging the signals obtained during the light emission off-periods of the light emitting elements **3** and **4** are subtracted from the DC components S1*d*on and S2*d*on resulting from time-averaging the signals obtained during the light emission on-periods of the light emitting elements **3** and **4**, respectively. As a result, the DC components S1*d* and S2*d* attributable to the lights from the light emitting elements **3** and **4** can be calculated by excluding the component attributable to the extraneous light noise.

Furthermore, the arithmetic processing unit **15** can calculate the absorbance ratio R**12** based on a ratio of the normalized signal S**10**, which is obtained as a first ratio of the amplitude ΔS1*a* of a first AC component S1*a* and a first DC component S1*d*, to the normalized signal S**20**, which is obtained as a second ratio of the amplitude ΔS2*a* of a second AC component S2*a* and a second DC component S2*d*. As a result, even when the light emission intensity of the light emitter **2** and the light reception sensitivity of the light receiver **7** are different between the first and second wavelength bands, the resultant influence can be reduced. In addition, since the amplitudes ΔS1*a* and ΔS2*a* of the AC components S1*a* and S2*a* are normalized by employing the DC components S1*d* and S2*d* obtained after removing the influence of the extraneous light noise, the absorbance ratio R**12** of the living body B can be determined with high accuracy.

The modulation signals S1M and S2M are signals amplified at the amplification factor Gm by the preamplifier **8** and the post-amplifier **10**. On that occasion, since a DC noise component, etc., excluded from the modulation signals S1M and S2M by the filter circuit **9**, they undergo a smaller influence of the extraneous light noise than the first and second detection signals S**1** and S**2**. Therefore, saturation of both the amplifiers **8** and **10** caused by the extraneous light noise can be suppressed. Moreover, since respective amplitude ranges of the modulation signals S1*m* and S2*m* are stabilized, respective amplitude ranges of the modulation signals S1M and S2M after the amplification can be each set to a value comparable to that of the input range of the AD converter **14**. Accordingly, a signal to noise ratio (S/N) can be stably ensured at a satisfactory level. In addition, since minimum resolution representing resolution per the least significant bit of the AD converter **14** is improved, a bit width of the AD converter **14** can be reduced, and the cost can also be reduced.

In the first embodiment described above, steps **1** to **3** in FIG. **2** represent a practical example of DC component calculation means. Step **1** in FIG. **2** represents a practical example of total component calculation means. Step **2** in FIG. **2** represents a practical example of noise component calculation means. Step **3** in FIG. **2** represents a practical example of noise excluded component calculation means. Step **4** in FIG. **2** represents a practical example of AC component calculation means. Step **6** in FIG. **2** represents a practical example of absorbance ratio calculation means.

FIG. **4** illustrates an optical sensor device **21** according to a second embodiment. The optical sensor device **21** detects, for example, a photo-plethysmographic signal (pulse wave signal) corresponding to the pulse of a living body B as a measurement target.

A light emitter **22** is constituted by first and second light emitting elements **23** and **24** that output lights in first and second wavelength bands different from each other, respectively. The first and second light emitting elements **23** and **24** are each constituted by, e.g., a light emitting diode (LED). Herein, the first light emitting element **23** emits, e.g., red light in a band of 700 nm, and the second light emitting element **24** emits, e.g., infrared light in a band of 900 nm.

First and second drive circuits **25** and **26** are connected to the first and second light emitting elements **23** and **24**, respectively. The first and second light emitting elements **23** and **24** emit continuously lasting lights or intermittently blanking lights in accordance with drive currents supplied from the first and second drive circuits **25** and **26**, respectively.

Herein, the first and second light emitting elements **23** and **24** may alternately emit the lights in a time-division manner, for example. Alternatively, when a light receiver **27** can separately receive the lights in the first and second wavelength bands, the first and second light emitting elements **23** and **24** may emit the lights at the same timing in synchronism. The first and second light emitting elements **23** and **24** may be each constituted using a vertical cavity surface emitting laser (VCSEL) or a laser diode (LD).

The light receiver **27** is constituted by, e.g., a light receiving element, such as a photodiode (PD). The light receiver **27** receives an optical signal and outputs it after photoelectric conversion to an electrical signal, e.g., a current signal or a voltage signal. More specifically, the light receiver **27** receives the lights emitted from the light emitting elements **23** and **24** and reflected by or transmitted through the living body B, converts the received lights to first and second detection signals S**1** and S**2** in the form of electrical signals, and outputs the detection signals S**1** and S**2** to a preamplifier **28**. Here, the first detection signal S**1** is a signal corresponding to the light in the first wavelength

band, and the second detection signal S2 is a signal corresponding to the light in the second wavelength band.

The light receiving element constituting the light receiver **27** may be a phototransistor, as another example. The light receiver **27** may be constituted using a single light receiving element, or using a plurality of light receiving elements, which receive lights in different wavelength bands by employing optical filters, for example.

The preamplifier **28** is constituted using, e.g., an operational amplifier. An input terminal of the preamplifier **28** is connected to the light receiver **27**. The preamplifier **28** amplifies the detection signals S1 and S2, output from the light receiver **27**, at an amplification factor Gx and outputs the amplified signals to a separation circuit **29**.

The separation circuit **29** is constituted by first and second branch lines **30** and **31**, which are connected in parallel to an output terminal of the preamplifier **28**, and by a filter circuit **32**, which functions as a high-pass filter connected to an intermediate point of the second branch line **31**. The filter circuit **32** is constituted by a capacitor **32**A that serves as a coupling capacitor connected between the preamplifier **28** and a post-amplifier **33**.

The first branch line **30** transmits the first and second detection signals S1 and S2 output from the preamplifier **28**, as they are, including the DC components S1*d* and S2*d*. Therefore, the first branch line **30** serves as a DC component transmission path for transmitting the DC components S1*d* and S2*d* of the first and second detection signals S1 and S2.

On the other hand, the capacitor **32**A functioning as a coupling capacitor is disposed in the second branch line **31**. Because the DC components S1*d* and S2*d* of the first and second detection signals S1 and S2 are blocked by the capacitor **32**A, the second branch line **31** serves as an AC component transmission path for transmitting the AC components S1*a* and S2*a* of the first and second detection signals S1 and S2. The capacitance of the capacitor **32**A is set depending on frequencies of the AC components S1*a* and S2*a* of the first and second detection signals S1 and S2, which are to be passed through the capacitor **32**A.

When the first and second AC components S1*a* and S2*a* are sufficiently smaller (e.g., 1/10 or less) than the first and second DC components S1*d* and S2*d*, the first and second detection signals S1 and S2 become substantially the same signals as the DC components S1*d* and S2*d*, respectively. Therefore, the first branch line **30** transmits the first and second detection signals S1 and S2 as they are. On the contrary, when the first and second AC components S1*a* and S2*a* are comparable to the first and second DC components S1*d* and S2*d*, or when the first and second AC components S1*a* and S2*a* are larger than the first and second DC components S1*d* and S2*d*, a low-pass filter, e.g., an integrator, may be connected to the first branch line **30**.

The post-amplifier **33** is an amplifier for amplifying the first and second AC components S1*a* and S2*a*. The post-amplifier **33** is connected to the second branch line **31** on the output side of the capacitor **32**A. The post-amplifier **33** amplifies the first and second AC components S1*a* and S2*a* of the first and second detection signals S1 and S2 at an amplification factor Gy, and then outputs first and second AC components S1A and S2A after the amplification. The post-amplifier **33** is constituted using an operational amplifier, for example, and it constitutes an amplification circuit **34** in combination with the preamplifier **28**. Here, an amplification factor Gd of the first and second DC components S1*d* and S2*d* of the first and second detection signals S1 and S2 is set by the preamplifier **28**, and the amplification factor Gd is equal to the amplification factor Gx (i.e., Gd=Gx). On the other hand, an amplification factor Ga of the first and second AC components S1A and S2A of the first and second detection signals S1 and S2 is set by both the preamplifier **28** and the post-amplifier **33**, and the amplification factor Ga is equal to the product of the amplification factor Gx and the amplification factor Gy (i.e., Ga=Gx×Gy). Thus, the amplification circuit **34** amplifies the DC components S1*d* and S2*d* and the AC components S1*a* and S2*a* of the first and second detection signals S1 and S2, which are separated by the separation circuit **29**, at the separate amplification factors Gd and Ga, respectively.

When the AC components S1*a* and S2*a* of the first and second detection signals S1 and S2 are photo-plethysmographic signals, the AC components S1*a* and S2*a* changing depending on the blood flow in the living body B are smaller than the DC components S1*d* and S2*d* corresponding to the reflected or transmitted lights directly obtained from the living body B. In the amplification circuit **34**, therefore, the amplification factor Ga for the AC components S1*a* and S2*a* is set to be larger than the amplification factor Gd for the DC components S1*d* and S2*d* such that the amplitudes of those components are set to values comparable to the amplitude range of an AD converter **37** described below.

The processing circuit **35** is mainly constituted by a multiplexer **36**, the AD converter **37**, and an arithmetic processing unit **38**.

The multiplexer **36** is connectable to the first branch line **30** of the separation circuit **29**, and to the second branch line **31** thereof at a downstream position of the post-amplifier **33**. The multiplexer **36** alternately connects the first and second branch lines **30** and **31** to the AD converter **37** in a time-division manner, for example.

When the multiplexer **36** is connected to the first branch line **30**, the AD converter **37** converts the DC components S1*d* and S2*d* of the first and second detection signals S1 and S2 from analog signals to digital signals, and when the multiplexer **36** is connected to the second branch line **31**, the AD converter **37** converts the AC components S1A and S2A of the first and second detection signals S1 and S2 from analog signals to digital signals. At that time, the DC components S1*d* and S2*d* and the AC components S1A and S2A of the first and second detection signals S1 and S2 are each set by the amplification circuit **34** to a value comparable to the input range of the AD converter **37**. Therefore, the AD converter **37** can convert the DC components S1*d* and S2*d* and the AC components S1A and S2A to the digital signals by employing the entire input range thereof.

The first and second detection signals S1 and S2 are directly input, as the DC components S1*d* and S2*d*, to the AD converter **37**. When the AC components S1*a* and S2*a* are sufficiently smaller (e.g., 1/10 or less) than the DC components S1*d* and S2*d* and are comparable to the resolution of the AD converter **37**, the AC components S1*a* and S2*a* are removed when the DC components S1*d* and S2*d* are converted to the digital signals by the AD converter **37**. On the other hand, when the AC components S1*a* and S2*a* are so large as not negligible, it is preferable to previously remove the AC components S1*a* and S2*a* contained in the DC components S1*d* and S2*d* by employing a low-pass filter, or to determine time-average values of the DC components S1*d* and S2*d* having been converted to the digital signals.

The arithmetic processing unit **38** is constituted by a microcomputer, for example. By executing a processing program illustrated in FIG. **5**, the arithmetic processing unit **38** restores the first and second detection signals S1 and S2 before the amplification based on the DC components S1*d* and S2*d* and the AC components S1A and S2A, which are

output from the AD converter **37**, and further determines an absorbance ratio R**12** of the living body B. The processing program illustrated in FIG. **5** is executed, for example, each time the digital signals of the DC components S**1***d* and S**2***d* and the AC components S**1**A and S**2**A are updated by the AD converter **37**.

In more detail, the arithmetic processing unit **38** executes a ratio restoration process, illustrated in step **11** of FIG. **5**, by converting the DC components S**1***d* and S**2***d* and the AC components S**1**A and S**2**A of the first and second detection signals S**1** and S**2** based on the amplification factors Gd and Ga such that respective amplitudes of those components are restored to have the same ratios as those before the amplification by the amplification circuit **34**. On that occasion, the amplification factors Gd and Ga are different from each other by the amplification factor Gy of the post-amplifier **33**, and the amplitudes of the AC components S**1**A and S**2**A input to the arithmetic processing unit **38** are larger in amplitude than that of the DC components S**1***d* and S**2***d* by the amplification factor Gy of the post-amplifier **33**. In view of such a difference, the arithmetic processing unit **38** calculates restored AC components S**1***ar* and S**2***ar* by dividing the AC components S**1**A and S**2**A by the amplification factor Gy as expressed in the following formula 3. As a result, the DC components S**1***d* and S**2***d* and the AC components S**1***ar* and S**2***ar* are restored to have the ratios between their amplitudes (i.e., the amplitude ratios) before the amplification.

$$S1ar = \frac{S1A}{Gy} \qquad \text{[Math. 3]}$$

$$S2ar = \frac{S2A}{Gy}$$

Next, in step **12**, a combining process of combining the restored AC components S**1***ar* and S**2***ar* with the DC components S**1***d* and S**2***d*, respectively, is executed to obtain first and second restoration signals SR**1** and SR**2** resulting from restoring the first and second detection signals S**1** and S**2** before the amplification. More specifically, the first and second restoration signals SR**1** and SR**2** are calculated by adding the restored AC components S**1***ar* and S**2***ar* to the DC components S**1***d* and S**2***d*, respectively, as expressed in the following formula 4.

$$SR1=S1d+S1ar$$

$$SR2=S2d+S2ar \qquad \text{[Math. 4]}$$

Next, in step **13**, a normalized signal calculation process is executed to normalize respective amplitudes ΔS**1***ar* and ΔS**2***ar* of the AC components S**1***ar* and S**2***ar* by employing the DC components S**1***d* and S**2***d*, respectively. Here, the amplitudes ΔS**1***ar* and ΔS**2***ar* are obtained by restoring respective amplitudes ΔS**1**A and ΔS**2**A of the AC components S**1**A and S**2**A after the amplification to the states before the amplification, i.e., by dividing the amplitudes ΔS**1**A and ΔS**2**A by the amplification factor Gy. Normalized signals S**10** and S**20** are calculated as the first and second ratios by dividing the amplitudes ΔS**1***ar* and ΔS**2***ar* by the DC components S**1***d* and S**2***d*, respectively, in accordance with the following formula 5.

$$S10 = \frac{\Delta S1ar}{S1d} \qquad \text{[Math. 5]}$$

-continued

$$S20 = \frac{\Delta S2ar}{S2d}$$

Next, in step **14**, an absorbance ratio calculation process is executed to calculate the absorbance ratio R**12** by employing the normalized signals S**10** and S**20**. More specifically, the absorbance ratio R**12** is calculated by dividing the normalized signal S**10** corresponding to the first wavelength by the normalized signal S**20** corresponding to the second wavelength in accordance with the above-described formula 2.

The arithmetic processing unit **38** may produce, in addition to the absorbance ratio R**12**, biological information, such as a degree of oxygen saturation, acceleration pulse wave, and pulse fluctuation, based on the first and second detection signals S**1** and S**2**. Furthermore, the arithmetic processing unit **38** is connected to the first and second drive circuits **25** and **26** to establish synchronism between the light emission by the first and second light emitting elements **23** and **24** and the light reception by the light receiver **27** based on the operations of the first and second drive circuits **25** and **26**.

The optical sensor device **21** according to the second embodiment of the present invention is constituted as described above, and the operation of the optical sensor device **21** is described below.

First, a switch (not illustrated) of the optical sensor device **21** is turned on in a state that the light emitter **22** and the light receiver **27** are disposed near the living body B. Upon the turning-on of the switch, the first and second light emitting elements **23** and **24** of the light emitter **22** output the lights in the first and second wavelength bands, respectively. The light receiver **27** receives the emitted lights after being reflected by or transmitted through the living body B, and outputs the first and second detection signals S**1** and S**2** corresponding to the first and second wavelength bands, respectively. The first and second detection signals S**1** and S**2** are separated by the separation circuit **29** into the DC components S**1***d* and S**2***d* and the AC components S**1**A and S**2**A, as illustrated in FIG. **6**, which are then input to the processing circuit **35** in the separated state. In the processing circuit **35**, the DC components S**1***d* and S**2***d* and the AC components S**1**A and S**2**A are converted to the digital signals by the AD converter **37**, and various processes are executed by the arithmetic processing unit **38**.

Herein, the DC components S**1***d* and S**2***d* and the AC components S**1**A and S**2**A are amplified respectively at the separate amplification factors Gd and Ga by the amplification circuit **34**. Accordingly, the respective amplitudes of the DC components S**1***d* and S**2***d* and the AC components S**1**A and S**2**A can be set to be comparable to each other, and those amplitudes can be set to values comparable to the amplitude range of the AD converter **37**. As a result, minimum resolution representing resolution per the least significant bit of the AD converter **37** is improved.

The foregoing point is described in more detail with reference to FIG. **7** representing a comparative example. An optical sensor device **41** according to the comparative example, illustrated in FIG. **7**, includes a light emitter **42**, a drive circuit **43**, a light receiver **44**, an amplifier **45**, and a processing circuit **46**. The processing circuit **46** is constituted by an AD converter **47** and an arithmetic processing unit **48**. In the optical sensor device **41**, a DC component Sd

and an AC component Sa of a detection signal S are amplified at the same amplification factor G by the amplifier **45**.

It is here assumed that the DC component Sd is 0.01 [V], the AC component Sa is about 1/10 (0.001 [V]) of the DC component Sd, and the DC component Sd is increased about 10 times (i.e., to 0.1 [V]) by the extraneous light noise. In such a case, assuming a maximum voltage level of the AD converter **47** to be 1 [V], the amplification factor G of the amplifier **45** is about 10 at maximum.

Furthermore, an amplitude ratio of the AC component Sa to the DC component Sd is not changed between the input side and the output side of the amplifier **45**, the AC component Sa cannot be detected with high accuracy unless the resolution of the AD converter **47** is set to be high. However, the maximum voltage level of the AD converter **47** is determined depending on a maximum value of the DC component Sd attributable to the extraneous light noise. Accordingly, when the resolution of the AD converter **47** is set to 10 bits, minimum resolution is, e.g., about 488 [μ:V/LSB] for each of the DC component Sd and the AC component Sa.

In contrast, in the optical sensor device **21** according to the second embodiment, the DC components S1*d* and S2*d* and the AC components S1A and S2A of the detection signals S1 and S2 are amplified respectively at the separate amplification factors Gd and Ga, for example, by employing the post-amplifier **33**. Even in the case where the amplitudes of the DC components S1*d* and S2*d* and the AC components S1*a* and S2*a* and the influence of the extraneous light noise on those amplitudes in the stage before the amplification are the same as in the comparative example described above, therefore, assuming the amplification factor Gd of the DC components S1*d* and S2*d* to be 1 and the amplification factor Ga of the AC components S1*a* and S2*a* to be 10, both the components can be input to the AD converter **37** with their amplitudes matched to the same value of 0.01 [V]. As a result, even if the DC components S1*d* and S2*d* are increased about 10 times (0.1 [V]) by the extraneous light noise, the maximum voltage level of the AD converter **37** can be reduced to 0.1 [V].

In addition, the amplification factor Ga of the AC components S1*a* and S2*a* is set to be larger than the amplification factor Gd of the DC components S1*d* and S2*d* such that the amplitudes of the AC components S1A and S2A after the amplification come close to the amplitude range of the AD converter **37**. Therefore, even when the resolution of the AD converter **37** is reduced to 8 bits, the minimum resolution for the AC components S1A and S2A is increased to, e.g., about 19.53 [μ:V/LSB]. In this regard, the minimum resolution for the DC components S1*d* and S2*d* is, e.g., about 19.53 [μV/LSB] when there is no influence of the extraneous light noise, and is, e.g., about 195.31 [μV/LSB] when there is an influence of the extraneous light noise.

According to the second embodiment, as described above, the minimum resolution of the AD converter **37** can be improved, and an AD converter having lower resolution can be used as the AD converter **37**. It is hence possible to reduce the power consumption and the manufacturing cost.

Thus, in the optical sensor device **21** according to the second embodiment, the first and second detection signals S1 and S2 output from the light receiver **27** are separated into the DC components S1*d* and S2*d* and the AC components S1*a* and S2*a* by the separation circuit **29**, and the DC components S1*d* and S2*d* and the AC components S1A and S2A, after being separated from each other, are amplified at the separate amplification factors Gd and Ga by the amplification circuit **34**, respectively. Therefore, the saturation of the amplification circuit **34** due to the extraneous light noise can be suppressed by reducing the amplification factor Gd of the DC components S1*d* and S2*d*. On the other hand, since other signals than the photo-plethysmographic signal are hardly superimposed on the AC components S1*a* and S2*a*, the amplification factor Ga for the AC components S1A and S2A can be sufficiently increased with respect to the signal range of the AD converter **37** that is a component of a digital processing unit. As a result, the signal to noise ratio (S/N) can be improved and stabilized.

Furthermore, since the DC components S1*d* and S2*d* and the AC components S1A and S2A can be all amplified up to ranges near the amplitude range of the AD converter **37**, the signal to noise ratio (S/N) can be stably ensured at a satisfactory level. In addition, since the amplitude range of each signal input to the AD converter **37** is stabilized, voltage resolution of the AD converter **37** per bit is widened. Accordingly, the bit width of the AD converter **37** can be reduced and cost reduction can be realized.

Moreover, since the arithmetic processing unit **38** executes the conversion such that the respective amplitudes of the DC components S1*d* and S2*d* and the AC components S1A and S2A of the digital signals take the same ratios as those before the amplification by the amplification circuit **34**, the DC components S1*d* and S2*d* and the AC components S1*ar* and S2*ar* can be restored at the same amplitude ratio as that when those components are output from the light receiver **27**. Therefore, the amplitudes ΔS1*ar* and ΔS2*ar* of the AC components S1*ar* and S2*ar* can be normalized respectively by employing the DC components S1*d* and S2*d* and the AC components S1*ar* and S2*ar* after being restored, for example.

Accordingly, the arithmetic processing unit **38** can calculate the absorbance ratio R**12** based on a ratio of the normalized signal S**10**, which is obtained as a first ratio of the amplitude ΔS1*ar* of a first AC component S1*ar* and a first DC component S1*d*, to the normalized signal S**20**, which is obtained as a second ratio of the amplitude ΔS2*ar* of a second AC component S2*ar* and a second DC component S2*d*. As a result, even when the light emission intensity of the light emitting elements **23** and **24** and the light reception sensitivity of the light receiver **27** are different between the first and second wavelength bands, the resultant influence can be reduced and the detection accuracy of the absorbance ratio R**12** can be increased.

Next, FIG. **8** illustrates a third embodiment of the present invention. The third embodiment is featured in that the light emitter emits light at a predetermined frequency set in advance, and that the separation circuit has, as a passage band, a band including the predetermined frequency of the light emitter and outputs an AC component modulated at the predetermined frequency of the light emitter. It is to be noted that, in the third embodiment, the same constituent elements as those in the second embodiment are denoted by the same reference symbols, and description of those constituent elements is omitted.

An optical sensor device **51** includes, substantially as in the optical sensor device **21** according to the second embodiment, the light emitter **22**, first and second drive circuits **52** and **53**, the light receiver **27**, a separation circuit **54**, an the amplification circuit **34**, and a processing circuit **56**.

Substantially like the first drive circuit **25** in the second embodiment, the first drive circuit **52** is connected to an arithmetic processing unit **57** in the processing circuit **56**, and it supplies a drive current to the first light emitting element **23**, thereby causing the first light emitting element

23 to emit blinking light. Here, the first drive circuit **52** supplies the drive current that is pulse-modulated at the predetermined frequency f set in advance. The predetermined frequency f is set to a frequency higher than a signal frequency (e.g., about several Hz) of the photo-plethysmographic signal. Preferably, the predetermined frequency f is set to a value (e.g., about several hundreds Hz) higher than the signal frequency of the photo-plethysmographic signal by ten or more times within a range in which the processing circuit **56** is able to execute processing.

In addition, the predetermined frequency f is set to a value (e.g., f=100 Hz) sufficiently lower than the changeover cycle (e.g., 400 Hz) of the AD converter **37** such that conversion to a digital signal can be performed by the AD converter **37**.

The second drive circuit **53** also has substantially the same configuration as that of the first drive circuit **52**. Thus, the second drive circuit **53** supplies a drive current, which is pulse-modulated at the same predetermined frequency f as that in the first drive circuit **52**, to the second light emitting element **24**, thereby causing the second light emitting element **24** to emit blinking light. On that occasion, for example, the first and second light emitting elements **23** and **24** may emit the lights at the same timing in synchronism, or may alternately emit the lights at timings different from each other.

The separation circuit **54** also has substantially the same configuration as that of the separation circuit **29** in the second embodiment. Thus, the separation circuit **54** is constituted by first and second branch lines **30** and **31**, which are connected in parallel to an output terminal of the preamplifier **28**, and by a filter circuit **55**, which functions as a high-pass filter connected to an intermediate point of the second branch line **31**. The filter circuit **55** is constituted by a capacitor **55**A that serves as a coupling capacitor connected between the preamplifier **28** and the post-amplifier **33**.

Here, the capacitance of the capacitor **55**A is set to a value allowing passage of signals of relatively high frequencies, including the signals having the drive frequency of the light emitting elements **23** and **24**. More specifically, the cutoff frequency of the high-pass filter, constituted by the capacitor **55**A, is set to a value as high as possible within a range allowing the signal of the predetermined frequency f set for the first and second drive circuits **52** and **53** to pass therethrough.

Because the light emitter **22** emits the lights blinking at the predetermined frequency f, the first and second detection signals S**1** and S**2** are each a signal obtained with amplitude modulation of the signal of the predetermined frequency f. On that occasion, because the capacitor **55**A cuts off signals of lower frequencies than the predetermined frequency f, the filter circuit **55** outputs the first and second AC components S**1***am* and S**2***am*, as modulation signals, which are obtained respectively from the first and second detection signals S**1** and S**2** through amplitude modulation at the predetermined frequency f. The post-amplifier **33** is an amplifier for amplifying the first and second AC components S**1***m* and S**2***m* which are the modulation signals. Accordingly, the first and second AC components S**1***am* and S**2***am*, both transferred through the second branch line **31**, are input to the processing circuit **56** after being amplified respectively to first and second AC components S**1**Am and S**2**Am by the post-amplifier **33**.

Substantially like the processing circuit **35** in the second embodiment, the processing circuit **56** is mainly constituted by the multiplexer **36**, the AD converter **37**, and the arithmetic processing unit **57**.

Here, the first and second DC components S**1***d* and S**2***d* and the first and second AC components S**1**Am and S**2**Am are input to the AD converter **37** in the processing circuit **56** through the multiplexer **36**, and the AD converter **37** converts the DC components S**1***d* and S**2***d* and the AC components S**1**Am and S**2**Am to digital signals. At that time, the AD converter **37** converts only plus-side values of the AC components S**1**Am and S**2**Am to digital signals, for example. The DC components S**1***d* and S**2***d* and the AC components S**1**Am and S**2**Am, having been converted to the digital signals, are input to the arithmetic processing unit **57** that is constituted by, e.g., a microcomputer.

By executing a processing program illustrated in FIG. **9**, the arithmetic processing unit **57** restores the first and second detection signals S**1** and S**2** before the amplification based on the DC components S**1***d* and S**2***d* and the AC components S**1**Am and S**2**Am, which are output from the AD converter **37**, and further determines an absorbance ratio R**12** of the living body B. In other words, the arithmetic processing unit **57** converts the DC components S**1***d* and S**2***d* and the AC components S**1**Am and S**2**Am by employing the amplification factor Gy of the post-amplifier **33** such that amplitude ratios between the DC components S**1***d* and S**2***d* and the AC components S**1**Am and S**2**Am come back to the states before the amplification by the post-amplifier **33**.

In more detail, the arithmetic processing unit **57** executes a ratio restoration process, illustrated in step **21** of FIG. **9**. In step **21**, the arithmetic processing unit **57** converts the DC components S**1***d* and S**2***d* and the AC components S**1**Am and S**2**Am of the first and second detection signals S**1** and S**2** based on the amplification factors Gd and Ga such that respective amplitudes of those components are restored to have the same ratios as those before the amplification by the amplification circuit **34**. More specifically, the arithmetic processing unit **57** executes arithmetic operations, similar to the above-described formula 3, to calculate restored AC components S**1***ar* and S**2***ar* by dividing the AC components S**1**Am and S**2**Am by the amplification factor Gy.

Next, in step **22**, a combining process of combining the restored AC components S**1***ar* and S**2***ar* with the DC components S**1***d* and S**2***d*, respectively, is executed. More specifically, the arithmetic processing unit **57** executes arithmetic operations, similar to the above-described formula 4, to obtain first and second restoration signals SR**1** and SR**2**, which are resulted from restoring the first and second detection signals S**1** and S**2** before the amplification, by adding the restored AC components S**1***ar* and S**2***ar* to the DC components S**1***d* and S**2***d*, respectively.

As illustrated in FIG. **10**, the AC components S**1***ar* and S**2***ar* obtained after amplification correction of the AC components S**1**Am and S**2**Am contain the components attributable to the reflected or transmitted lights directly obtained from the living body B. To avoid those components from being superimposed doubly, the first and second restoration signals SR**1** and SR**2** may be calculated by adding the restored AC components S**1***ar* and S**2***ar* to DC components S**1***d*off and S**2***d*off, which are obtained during the light emission off-periods of the emitting elements **23** and **24** and which are contained in the DC components S**1***d* and S**2***d*, respectively.

Next, in step **23**, a noise component calculation process is executed to obtain the DC components S**1***d*off and S**2***d*off attributable to the extraneous light noise by employing the detection signals S**1** and S**2** during the light emission off-periods of the light emitter **22**. More specifically, as illustrated in FIG. **10**, when the light emitting elements **23** and **24** do not emit the lights, DC components S**1***d***0** and

S2*d*0 attributable to the lights emitted from the light emitting elements **23** and **24** are not detected, and only the DC components S1*d*off and S2*d*off attributable to the extraneous light noise are detected. Therefore, the DC components S1*d*off and S2*d*off attributable to the extraneous light noise can be obtained by extracting, from the DC components S1*d* and S2*d*, signals obtained during the light emission off-periods of the light emitting elements **23** and **24**.

Next, in step **24**, a noise excluded component calculation process is executed to obtain the DC components S1*d*0 and S2*d*0 excluding the extraneous light noise. More specifically, the detection signals S1 and S2 during the light emission on-periods of the light emitter **22** are extracted to obtain DC components S1*d*on and S2*d*on attributable to not only the extraneous light noise, but also the lights from the light emitting elements **23** the 24, and the DC components S1*d*off and S2*d*off attributable to the extraneous light noise are subtracted from the DC components S1*d*on and S2*d*on. As a result, the DC components S1*d*0 and S2*d*0 from which the extraneous light noise has been excluded are calculated.

Next, in step **25**, a normalized signal calculation process is executed to normalize the amplitudes ΔS1*ar* and ΔS2*ar* of the AC components S1*ar* and S2*ar* by employing the DC components S1*d*0 and S2*d*0, respectively. Here, the amplitudes ΔS1*ar* and ΔS2*ar* are ones obtained by restoring the amplitudes ΔS1A and ΔS2A of the AC components S1Am and S2Am after the amplification to the states before the amplification. The normalized signals S10 and S20 are calculated as the first and second ratios by dividing the amplitudes ΔS1*ar* and ΔS2*ar* by the DC components S1*d*0 and S2*d*0, respectively, in accordance with the following formula 6.

[Math. 6]

$$S10 = \frac{\Delta S1ar}{S1d0}$$

$$S20 = \frac{\Delta S2ar}{S2d0}$$

While, in step **25**, the normalized signals S10 and S20 are obtained using the DC components S1*d*0 and S2*d*0, the normalized signals S10 and S20 may be obtained based on only the AC components S1Am and S2Am. In such a case, as seen from FIG. **10**, values S1A0 and S2A0 corresponding to the DC components excluding the extraneous light noise can be calculated by subtracting, for the AC components S1Am and S2Am, the AC components S1Aoff and S2Aoff during the light emission off-periods from time-average values of the AC components S1Aon and S2Aon during the light emission on-periods of the light emitting elements **23** and **24**, respectively. By dividing the amplitudes ΔS1A and ΔS2A of the AC components S1Am and S2Am by the values S1A0 and S2A0, therefore, the amplitudes ΔS1A and ΔS2A can be normalized and the normalized signals S10 and S20 can be obtained.

Next, in step **26**, an absorbance ratio calculation process is executed to calculate the absorbance ratio R12 by employing the normalized signals S10 and S20. More specifically, the absorbance ratio R12 is calculated by dividing the normalized signal S10 corresponding to the first wavelength by the normalized signal S20 corresponding to the second wavelength in accordance with the above-described formula 2.

Thus, the third embodiment can also provide similar advantageous effects to those in the second embodiment. According to the third embodiment, particularly, since the light emitter **22** emits the lights at the predetermined frequency f and the separation circuit **54** outputs the AC components S1*am* and S2*am* modulated at the predetermined frequency f of the light emitter **22**, the cutoff frequency of the separation circuit **54** can be set to a higher value and the capacitance of the capacitor **55**A can be reduced.

To explain in more detail, the photo-plethysmographic signal is a low-frequency signal of about several Hz corresponding to the pulse of the living body. To separate the photo-plethysmographic signal, therefore, the cutoff frequency is to be as low as about several Hz, and a capacitor having a large capacitance of, e.g., about several hundreds μF is required. In contrast, in the third embodiment, the separation circuit **54** is just required to allow passage of signals of the predetermined frequency f, which is higher than the frequency of the photo-plethysmographic signal, in order to separate the AC components S1*am* and S2*am* modulated at the predetermined frequency f of the light emitter **22**. Therefore, the cutoff frequency of the separation circuit **54** can be set to a higher value, and the capacitance of the capacitor **55**A can be reduced to be smaller than 1 μF, for example. As a result, reduction in size and cost can be realized.

Furthermore, the DC components S1*d*off and S2*d*off attributable to the extraneous light noise alone can be extracted by employing digital signal data of the DC components S1*d* and S2*d* during the light emission off-periods. Thus, since the DC components S1*d*off and S2*d*off attributable to the extraneous light noise can be excluded respectively from the detected DC components S1*d* and S2*d*, the amplitudes ΔS1*ar* and ΔS2*ar* of the AC components S1*ar* and S2*ar* can be normalized without suffering from the influence of the extraneous light noise. As a result, the absorbance ratio R12 of the living body B can be obtained with high accuracy.

In the second and third embodiments described above, step **11** in FIG. **5** and step **21** in FIG. **9** represent practical examples of ratio restoration means. Step **14** in FIG. **5** and step **26** in FIG. **9** represent practical examples of absorbance ratio calculation means. Step **23** in FIG. **9** represents a practical example of noise component calculation means.

While, in each of the above-described embodiments, the light emitters **2** and **22** are each configured to emit the lights of two different wavelengths, they may be each configured to emit light of one wavelength or lights of three or more wavelengths.

Moreover, the foregoing embodiments have been each described above in connection with an example in which the present invention is applied to the optical sensor device **1**, **21** or **51** for detecting the photo-plethysmographic signal of the living body B. However, application fields of the present invention are not limited to that type of optical sensor device, and the present invention can be applied to various types of optical sensor devices for detecting lights reflected by or transmitted through measurement targets.

REFERENCE SIGNS LIST

1, **21**, **51** optical sensor devices
2, **22** light emitters
3, **4**, **23**, **24** light emitting elements
7, **27** light receivers
9, **32**, **55** filter circuits
10, **33** post-amplifiers (amplifiers)
11, **34** amplification circuits
14, **37** AD converters

15, 38, 57 arithmetic processing units
29, 54 separation circuits

The invention claimed is:

1. An optical sensor device, comprising:
a light emitter configured to periodically emit light at a predetermined frequency toward a measurement target;
a light receiver configured to detect at least one of reflected light and diffused light from the measurement target, and to output a modulated electrical signal based on the detected light;
a filter circuit configured to filter the modulated electrical signal at the predetermined frequency and to output a modulation signal;
an amplifier configured to amplify the modulation signal;
an AD converter configured to convert the modulation signal to a digital signal;
an arithmetic processing unit coupled to the AD converter and configured to calculate a DC component and an AC component of the electrical signal based on the digital signal; and
a separation circuit including the filter circuit and configured to separate the modulation signal and the DC component of the electrical signal,
wherein the AD converter is further configured to convert the DC component of the electrical signal to a DC component digital signal, and
wherein the arithmetic processing unit is further configured to convert the modulation signal and the DC component digital signal based on an amplification factor of the amplifier, such that an amplitude ratio between the modulation signal and the DC component digital signal reaches a state before the amplification by the amplifier, and to calculate the AC component of the electrical signal based on the modulation signal.

2. The optical sensor device according to claim 1, wherein the arithmetic processing unit is further configured to calculate the DC component attributable to extraneous light noise based on a signal contained in the DC component of the electrical signal and obtained during an off-period of the light emitter.

3. An optical sensor device, comprising:
a light emitter configured to emit light toward a measurement target;
a light receiver configured to detect at least one of reflected light and diffused light from the measurement target, and output an electrical signal based on the detected light;
a separation circuit configured to separate the electrical signal into a DC component and an AC component;
an amplification circuit configured to amplify the DC component and the AC component, at first and second amplification factors, respectively;
an AD converter configured to convert the DC component and the AC component to first and second digital signals, respectively; and
an arithmetic processing unit configured to restore the DC component and the AC component of the electrical signal by converting the DC component and the AC component output as the first and second digital signals such that an amplitude ratio between the DC component and the AC component output as the digital signals obtains a state before the amplification by the amplification circuit.

4. An optical sensing method, comprising:
emitting light, by a light emitter, at a predetermined frequency towards a measurement target;
detecting, by a light receiver, at least one of reflected light and diffused light from the measurement target;
outputting, by the light receiver, a modulated electrical signal based on the detected light;
filtering, by a filter circuit, the modulated electrical signal at the predetermined frequency;
outputting, by the filter circuit, a modulation signal corresponding to the electrical signal;
amplifying, by an amplifier, the modulation signal;
converting, by an AD converter, the amplified modulation signal to a digital signal;
calculating, by a processor, a DC component and an AC component of the electrical signal based on the digital signal;
separating, by a separation circuit including the filter circuit, the modulation signal and the DC component of the electrical signal;
converting, by the AD converter, the DC component of the electrical signal to a DC component digital signal;
converting, by the processor, the modulation signal and the DC component digital signal based on an amplification factor of the amplifier, such that an amplitude ratio between the modulation signal and the DC component digital signal reaches a state before the amplification by the amplifier; and
calculating, by the processor, the AC component of the electrical signal based on the modulation signal.

5. The optical sensing method according to claim 4, further comprising calculating, by the processor, the DC component attributable to extraneous light noise based on a signal contained in the DC component of the electrical signal and obtained during an off-period of the light emitter.

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